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## STATUS OF SPV/CPV TESTING

**NAVAL SEA SYSTEMS COMMAND**




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1998 NASA AEROSPACE BATTERY  
WORKSHOP


October 27-29 1998 Huntsville AL

Introduction Slide.



**NSWC**  
CRANE DIVISION

STATUS OF SPV/CPV Testing At  
**CRANE DIVISION NSWC**



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**OUTLINE**

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**Common Pressure Vessel (CPV)**

- 10 Ahr, 2.5 in. Stainless Steel vessel - RNHC 10-1
  - Pack 3002L - >23600 (4.0 years) -- NASA Lewis Battery Program
- 45 Ahr, 3.5 in Heritage Cells
  - Pack 3005L - >12892 (2.2 years) -- Air Force Research Laboratory
  - Pack 3006L - > 13375(2.3 years) -- Air Force Research Laboratory
  - Pack 3007L - > 14 Accel. GEO cycles -- Air Force Research Laboratory
- 45 Ahr, 3.5 in Heritage Cells w/26% KOH and Wall Wick
  - Pack aaaaa - Catalyzed Wall Wick-- NASA Lewis Battery Program
  - Pack bbbbb - Non-Catalyzed Wall Wick
- 16 Ahr, 2.5 in Heritage Cells w/26% and 36% KOH
  - Pack ccccc -- NASA Lewis Battery Program
- 16 Ahr, 2.5 in Heritage Cells w/Design improvements
  - Pack ddddd 31% KOH -- NASA Lewis Battery Program
  - Pack ddddd 26% KOH
  - Pack ddddd 26% KOH and Catalyzed Wall Wick

**Single Pressure Vessel (SPV) 50 Ahr, 10 inch diameter**

- Pack 3003L - >20615 (3.5 years) -- NASA Lewis Space Station Program
- Pack 3004L - >13336 (2.3 years) -- Air Force Research Laboratory

This slide summarizes the SPV and CPV test that are on going or planned at Crane.

The SPV's will be covered in detail. Both NASA and Air Force have a battery under test.

The CPV's 2.5 in RNHC 10-1 design is a part of NASA Lewis CPV Technology program.

The 45 Ahr, 3.5 in Heritage cells were purchased by Air Force as a commercial procurement without a government spec. These tests are also a part of a NASA/ Air Force Joint program to evaluate CPV designs.

The remaining tests are planned. These cells evaluate the Design improvements that NASA has been evaluating on IPV cells. One group 16 Ahrs also includes design improvements incorporated by the manufacturer EP.

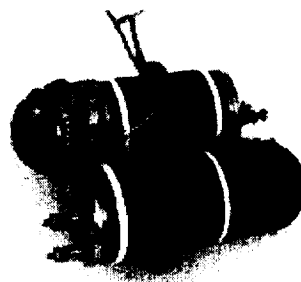


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CPV - RNHC10-1 Pack 3002L

NASA Lewis Battery - Pack 3002L  
Quantity - 10 cells (1 removed for DPA)  
Orbit 90 Minute LEO  
Test Temperature = 10°C  
DoD = 40%  
Discharge Current =  
    6.71 Amps for 36 Minutes  
Recharge - 104%  
Charge Current =  
    4.64 Amps for 54 Minutes  
  
Completed 23582 cycles 4 yrs  
as of 10/1/98



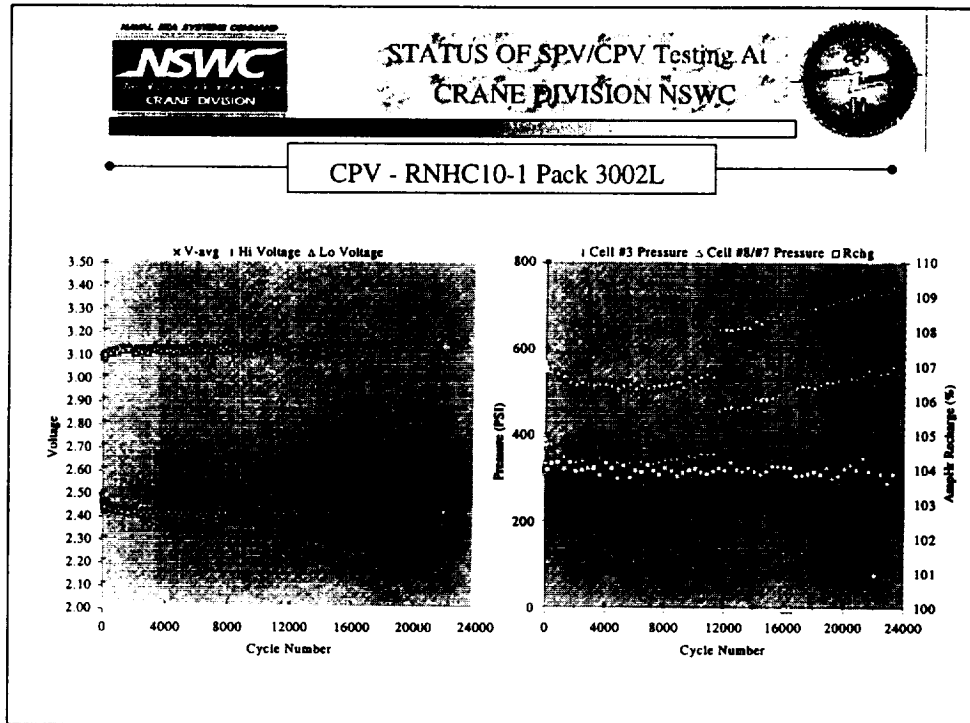
This Pack has completed 4 yrs of cycling under a LEO regime.

At 2 yrs one cell was removed and subjected to DPA. No anomalies were found.

Picture and cell design to be included..

This test sponsored by NASA Lewis CPV Technology Program.

POC Mr. Tom Miller

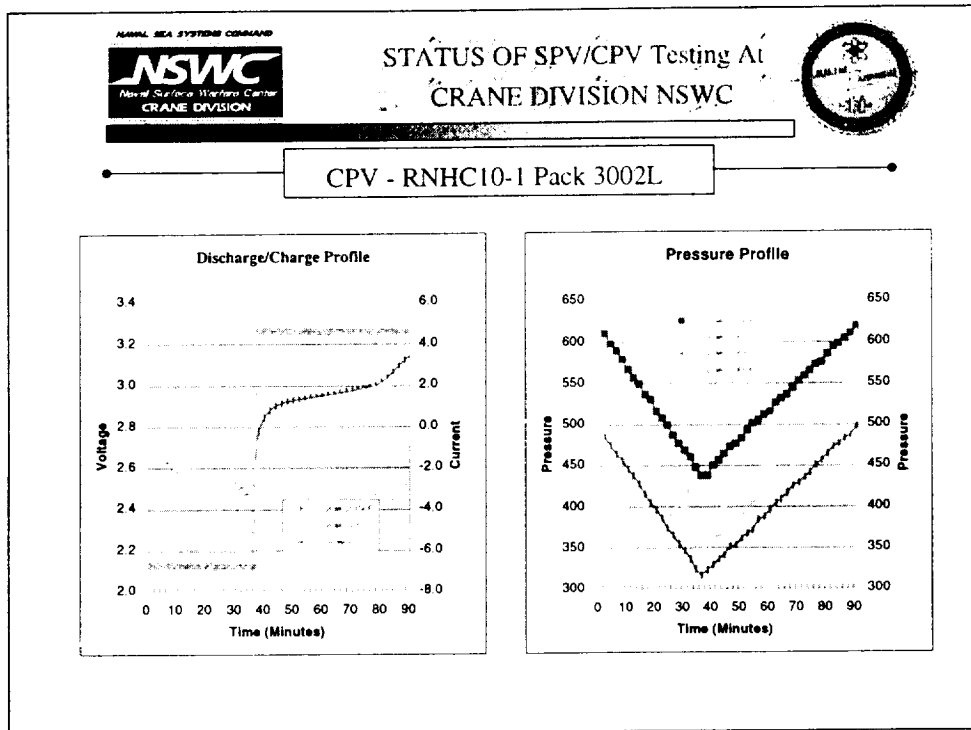


Life cycle voltage and pressure trend plot for Pack 3002L.

There has been little change in the end of discharge and charge voltages of the cells over the 23500 cycles. The change in pressure is due to a change in the measuring strain gage. Cell 8 (original pressure measurement) was removed for DPA. The step increase in the pressure curve occurred when Cell 7 replaced Cell 8 in recording data.

This test sponsored by NASA Lewis CPV Technology Program.

POC Mr. Tom Miller



Voltage and Pressure Plot of cycle 500 and 23500. NOTE there is no significant change in the discharge/charge curve and no change in the end of discharge voltage. One would expect a drop in the EOD voltage with life. The Pressure plot is normal in that pressure decreases initially then increases with cycling.

This test sponsored by NASA Lewis CPV Technology Program.  
POC Mr. Tom Miller

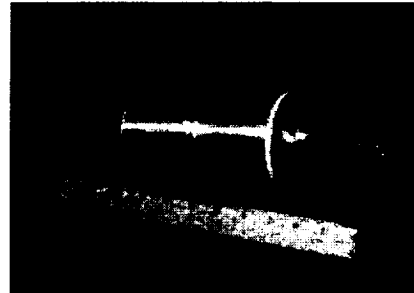


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## CPV 45 Ahr Air Force RNHC 45-1

Manuf. Eagle-Picher (Joplin)  
Model: RNHC 45-1  
Capacity 45 Ahr.  
Weight 2.66 Kg Length 13.9 in.  
Diameter 3.5 in.  
Plates 35 mils Thick  
Back to Back  
2 layer ZIRCAR  
31% KOH  
Received 8/95



Test Conditions  
18 cells were divided into 3 test packs.

The design parameters for the CPV cells was taken from Eagle-Picher commercial specification.

This test sponsored by Air Force Research Laboratory.  
POC Mr. Ralph James, Dan Radzykewycz.  
Technical Direction: The Aerospace Corporation  
POC Ms. Carole Hill



STATUS OF SPV/CPV Testing At  
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CPV 45 Ahr Air Force RNHC 45-1

LIFE CYCLE TEST CONDITIONS

|                | Pack 3005L            | Pack 3006L | Pack 3007L  |
|----------------|-----------------------|------------|---|
| Quantity       | 6 Cells               | 6 Cells    | 6 Cells   |
| Orbit          | LEO 90 Min.           | LEO 90 Min | Accel. GEO- 24Hrs<br>42 Day Cycle,<br>14 Day Trickle Charge |
| Test Temp      | 10 °C                 | -5 °C      | 10 °C   |
| DoD            | 40%                   | 40%        | 15%-75%-15%   |
| Discharge      | 36 Amps for 30 Min    |            | 28.12 Amps  |
| Recharge       | 104%                  | 104%       | 110%  |
| Charge         | 23.50 Amps for 46 Min |            | 2.25 (C/20) to 100%   |
| Trickle Charge | 3.10 Amps for 14 Min  |            | C/100 for remainder 24 Hrs                                  |
| Status10/1/98  | 12900                 | 13375      | 784 (14 Seasons)  |

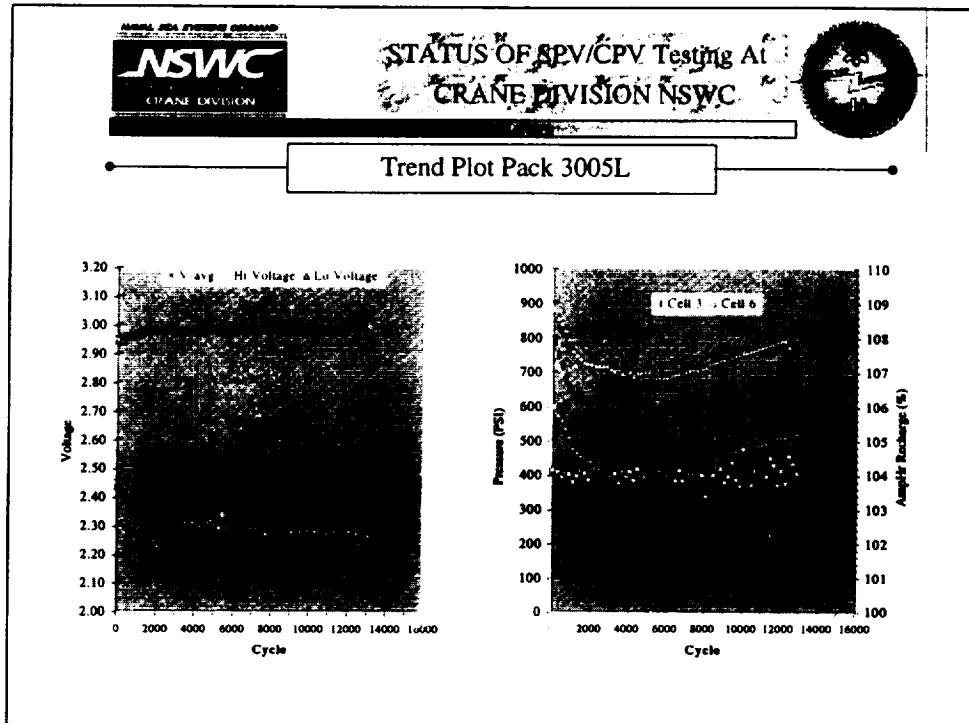
The cells are being subjected to conditions shown. The LEO Packs have completed over 2 years of test with no anomalies. The GEO pack has completed 14 accelerated seasons.

This test sponsored by Air Force Research Laboratory

POC Mr. Ralph James, Dan Radzykewycz.

Technical Direction: The Aerospace Corporation

POC Ms. Carole Hill



Life cycle voltage trend plot of Pack 3005L.

Life Cycle Pressure and Recharge Trend plot of Pack 3005L

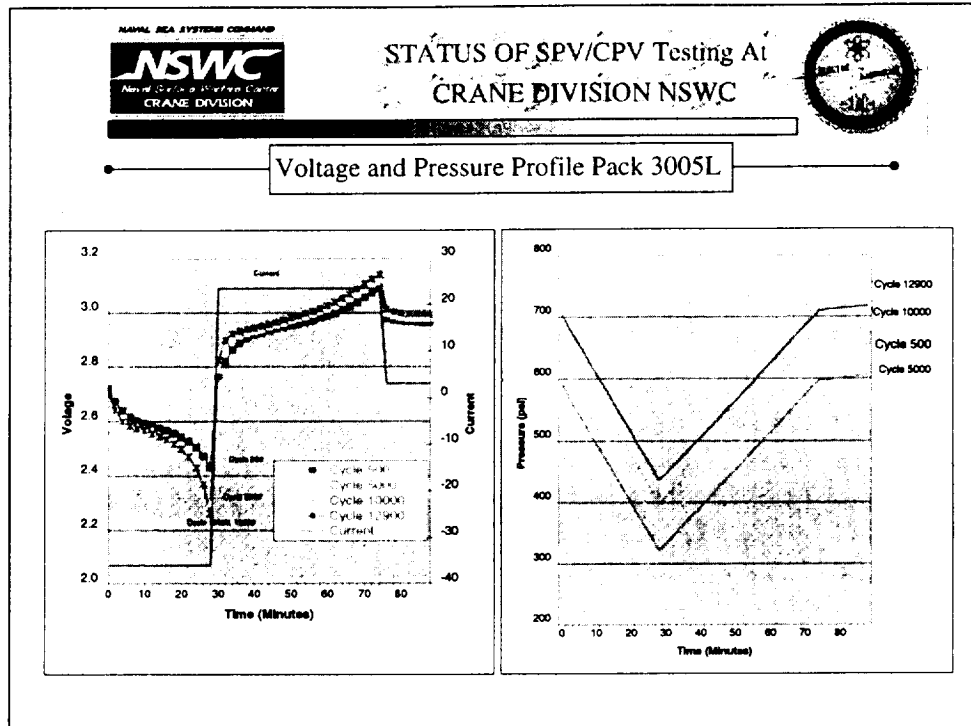
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POC Ms. Carole Hill





Typical discharge/charge cycle for Pack 3005L.

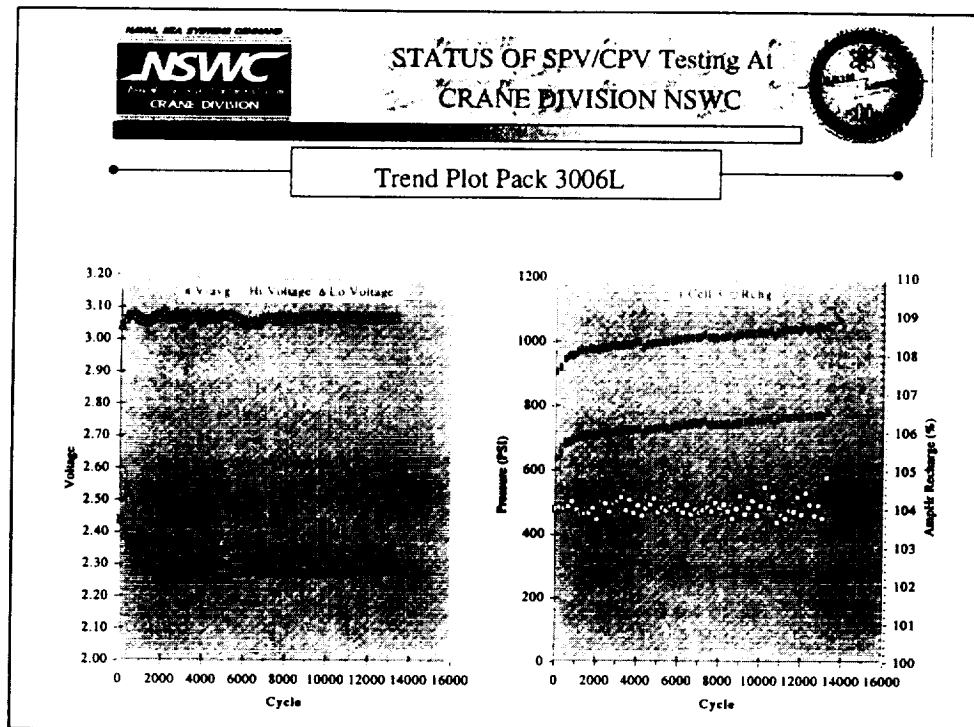
Typical pressure cycle for Pack 3005L

This test sponsored by Air Force Research Laboratory.

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Technical Direction: The Aerospace Corporation

POC Ms. Carole Hill



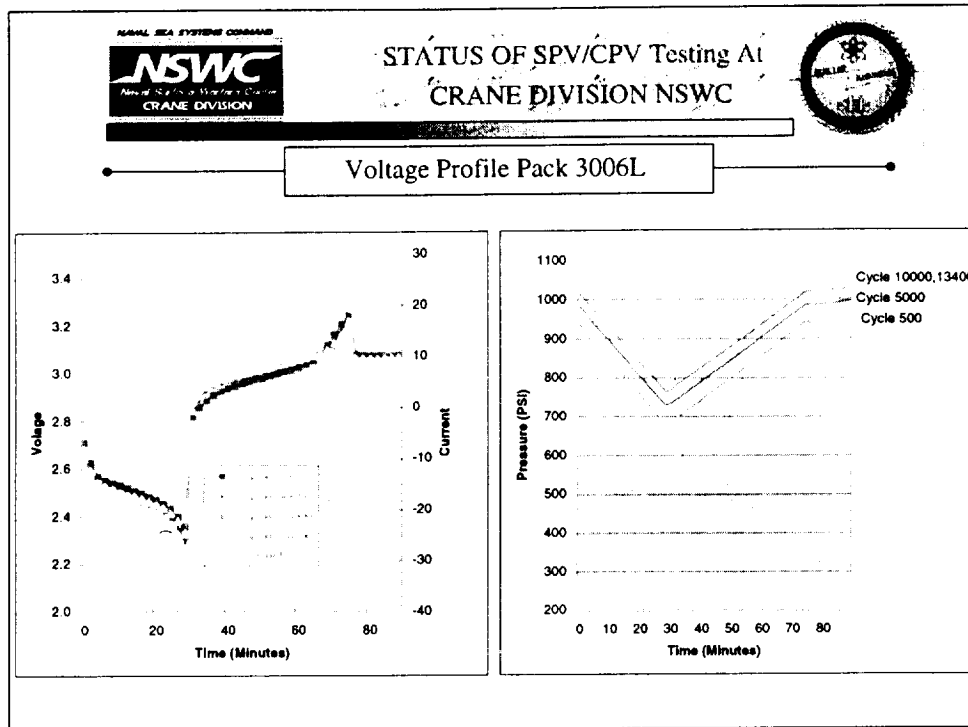
Life Cycle voltage trend plot of Pack 3006L. The pressure curve for this pack is different from that of Pack 3005L. The only difference between the two packs is the temperature. Pack 3006L is tested at -5C.

This test sponsored by Air Force Research Laboratory.

POC Mr. Ralph James, Dan Radzykewycz.

Technical Direction: The Aerospace Corporation

POC Ms. Carole Hill



Typical discharge/charge curve for Pack 3006L

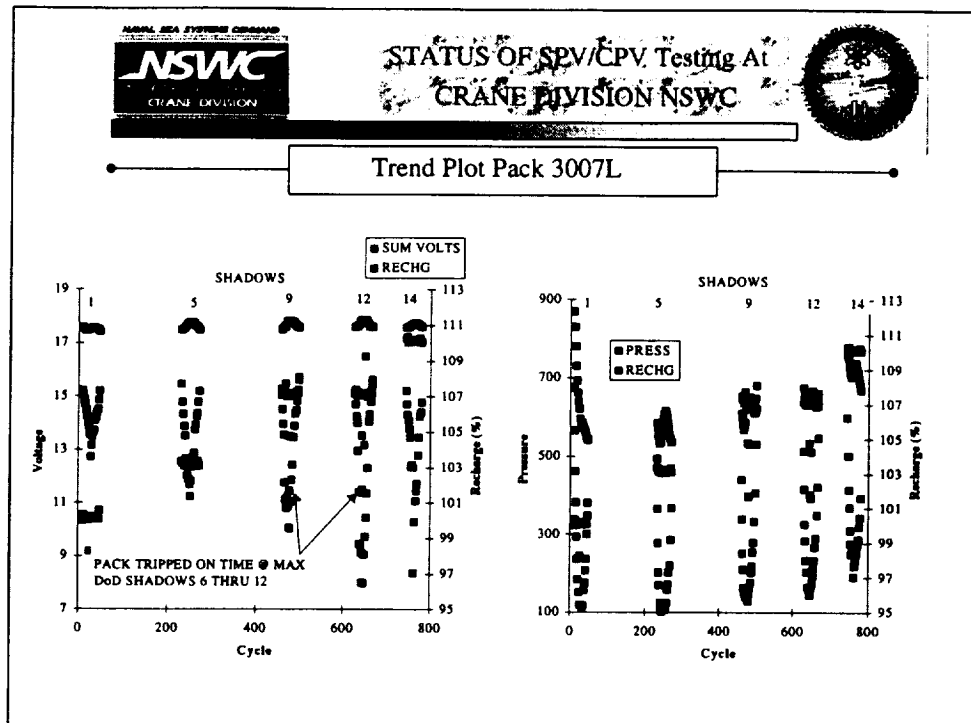
Typical pressure plot for Pack 3006L. This pack does not exhibit the characteristic pressure profile decrease from 500 to 5000 then increase for the remainder of life.

This test sponsored by Air Force Research Laboratory.

POC Mr. Ralph James, Dan Radzykewycz.

Technical Direction: The Aerospace Corporation

POC Ms. Carole Hill



Life Cycle Trend plot for Pack 3007L. The curves represent the discharge during the shadow period from 15% to 75% to 15% DoD.

This test sponsored by Air Force Research Laboratory.

POC Mr. Ralph James, Dan Radzykewycz.

Technical Direction: The Aerospace Corporation

POC Ms. Carole Hill



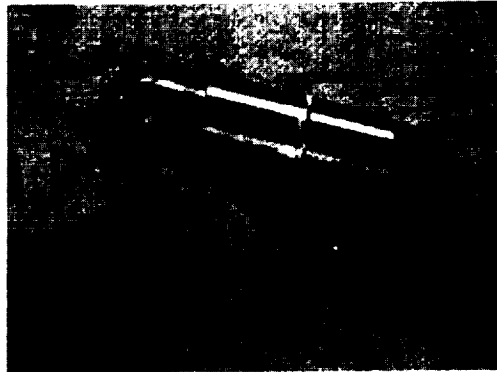
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### CPV RNHC 45-1 (Heritage)

Manufacturer Eagle-Picher Joplin  
Plates: 80% slurry sinter,  
35 mils thick from  
EP Colorado Springs  
Separator: Double layer ZIRCAR  
Wall wick: Zirconium-oxide  
Vessel wall Thickness - 0.030"  
Terminal Design - Axial  
Electrolyte - 26%

RNHC 45-7 - Non-catalyzed  
RNHC 45-9 - Catalyzed



Status: Received Sep 98 Awaiting Test Plan

Design parameters for RNHC 45-7 and 9 cells. The RNHC 45-1 Heritage design is the design previously shown in test as Packs 3005L, 3006L, and 3007L.

This test sponsored by NASA Lewis CPV Technology Program.

POC Mr. Tom Miller

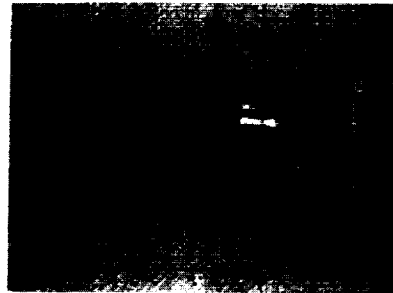


STATUS OF SPV/CPV Testing At  
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CPV RNHC 16-1 (Heritage)

Plates: 80% slurry sinter,  
30 mils thick from  
EP Colorado Springs  
Separator: Double layer ZIRCAR  
PV Wall: Teflonated  
Vessel wall Thickness - 0.026"  
Terminal Design - Rabbit-ear  
Electrolyte - RNHC 16-5 26%  
RNHC 16-7 31%



STATUS: Received Sep 98

Awaiting Test Plan

This test will evaluate the RNHC 16-1 design with modification of the electrolyte concentration to evaluate using 26% KOH in the cell.

This test sponsored by NASA Lewis CPV Technology Program.  
POC Mr. Tom Miller

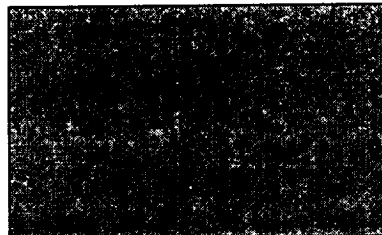


## STATUS OF SPV/CPV Testing At CRANE DIVISION NSWC



### CPV RNHC 16-9 New Design

Plates: 80% slurry sinter,  
30 mils thick from  
EP Colorado Springs  
Separator: Double layer ZIRCAR  
PV Wall: Teflonated  
Vessel wall Thickness - 0.023"  
Terminal Design - Rabbit-ear  
Electrolyte - RNHC 16-9 31%  
RNHC 16-11 26%  
RNHC 16-13 26% & Catalyzed Wall Wick



STATUS: Delivery scheduled for March 99

This test will evaluate design changes incorporated by the manufacturer and NASA improvements - 26% KOH and catalyzed wall wick

There are several design changes in the RNHC 16-9 cell. These include:


Incorporation of the fill tube in the positive terminal.

ZrO<sub>2</sub> coating of the CPV wall

Geometry change in the pressure vessel (Hydroformed/Spherical to Deep Drawn/Torospherical).


Other changes that may be proprietary to EP. Contact EP for details.

This test sponsored by NASA Lewis CPV Technology Program.  
POC Mr. Tom Miller



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Introduction - SPV

- 50 Ahr SPV
  - Eagle-Picher (JCI design)      NASA Lewis Research Center  
28050SCP                              International Space Station  
Tom Miller
  - Eagle-Picher (Modified JCI)      Air Force Research Laboratory  
SAR-10067                              Ralph James  
Dan Radzykewycz  
Carole Hill (Aerospace Corp)

Eagle-Picher (JCI Design) - This battery is completely a Johnson Controls Industry (JCI) design, manufactured, assembled, and tested at the JCI facility in Butler, WI. The battery was delivered in Nov 1994. This was after EP purchased the facility.

Eagle-Picher (Modified JCI) - This battery was contracted from EP in 1994 before the move from Butler. The battery was originally bid as the JCI design, but in Jan 95 EP moved the facility from Butler, WI to Joplin, MO. Parts for the battery had been manufactured at Butler but the battery had not been assembled. The plate handling during the move was suspect. Thus EP manufactured new plates using the EP process at Joplin and modified the battery size.



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Design - SPV

NASA LEWIS Pack 3003L

Manuf. Eagle-Picher (Bulter)  
Model: 28050SCP  
S/N S-154  
Capacity 50 Ahr.  
Weight 27.9Kg  
Length 29.968 in.  
Diameter 10.104 in.  
Cells 22 Flexible Containment  
Back to Back  
2 layer ZIRCAR  
31% KOH

Design Johnson Controls  
Plates Slurry - Johnson Controls  
Assembly Johnson Controls

Received 11/94

Air Force Pack 3004L

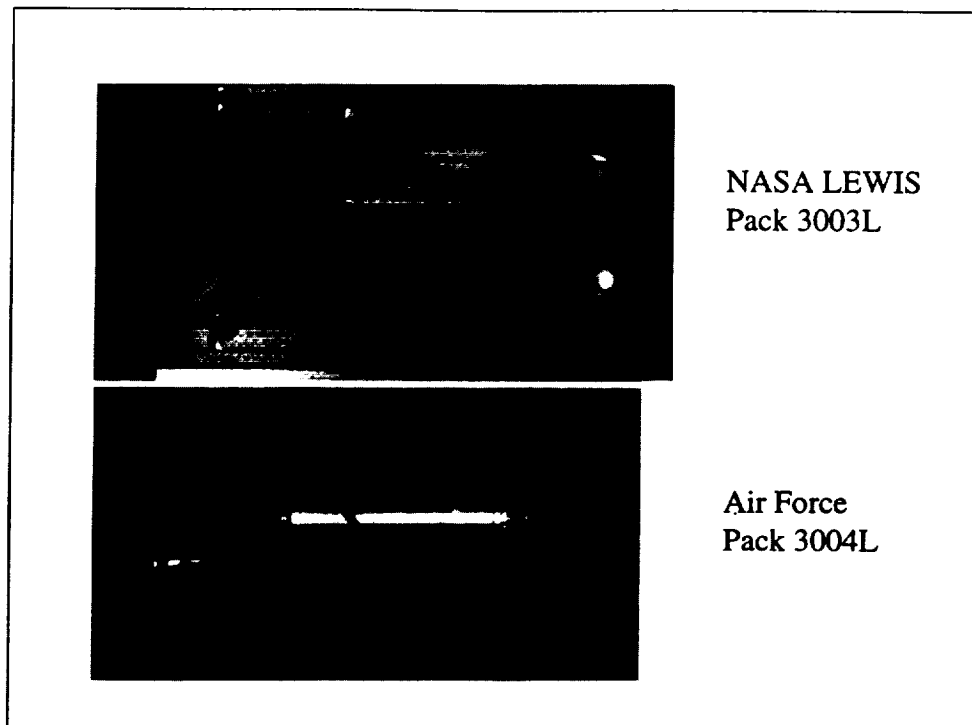
Manuf. Eagle-Picher (Joplin)  
Model: SAR-10067  
S/N S-164  
Capacity 50 Ahr.  
Weight 29.4Kg  
Length 24.682 in.  
Diameter 10.139 in.  
Cells 22 Flexible Containment  
Back to Back  
2 layer ZIRCAR  
31% KOH

Design JC modified by EP  
Plates Eagle-Picher (Joplin)  
Assembly Eagle-Picher (Joplin) using JC materials and molds.

Received 11/95

The differences in the design are shown in this slide. The AF battery is about 5 inches shorter and the plates were manufactured at Joplin. The assembly was at Joplin facility using the JCI materials and molds.

The design modification (shorter) reflect changes implemented in the commercial contract.



The differences in the design are shown in this slide. The EP design is about 5 inches shorter and the plates are manufactured at Joplin. The assembly was at Joplin facility using the JC materials and molds.



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## Acceptance Test

| NASA Lewis Battery - Pack 3003L |              |              | Air Force Battery - Pack 3004L |              |               |
|---------------------------------|--------------|--------------|--------------------------------|--------------|---------------|
| Conditioning 20 cycles 43 Ahr   |              |              | Conditioning 16 cycles 61. Ahr |              |               |
| Capacity Test 10°C              |              |              | Capacity Test 10 °C 60.80 Ahr  |              |               |
| Rate                            | Ahr to 22.0v | Ahr to 11.0v | Temp/Rate                      | Ahr to 22.0v | Ahr. to 11.0v |
| C/2                             | 43.09        | C/10 8.71    | -5 °C @ C                      | 69.71        | 1.69          |
| C                               | 43.09        | C/10 8.70    | 10°C @ C                       | 63.94        | 1.51          |
| 1.4C                            | 44.72        | C/10 8.37    | 10°C @ C/2                     | 64.85        | 1.51          |
| 2C                              | 42.63        | C/10 9.88    | 20°C @ C/2                     | 59.44        | 2.43          |
| Charge Retention 0°C            |              |              | 30°C @ C/2                     | 55.07        | 2.65          |
| C/2                             | 37.97        | C/10 2.94    | Overcharge Capacity            |              |               |
|                                 |              |              | 0°C @ C/2                      | 75.13        | 3.43          |
|                                 |              |              | Charge Retention 10°C          |              |               |
|                                 |              |              | C/2                            | 59.98        | 1.34          |

Pack 3003L - After 20 conditioning cycles the battery delivered on 43 Ahr. This was less then at the manufacturer's acceptance test. The battery had provided 54.6 Ahr. After some discussion it was decided to go ahead and test the battery.

Pack 3004L - This battery gave no problems during acceptance tests.



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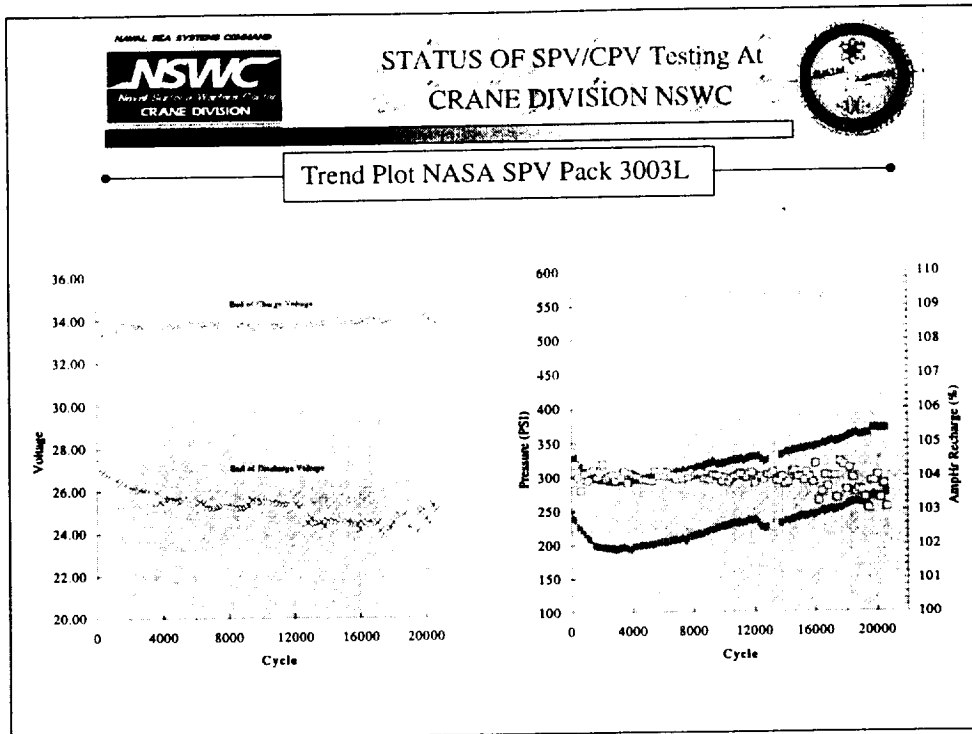
### Life Cycle Conditions

|   |   |
|---|---|
| NASA Lewis Battery - Pack 3003L                 | Air Force Battery - Pack 3004L                  |
| Orbit 90 Minute LEO                             | Orbit 90 Minute LEO                             |
| Test Temperature = 10°C                         | Test Temperature = 10°C                         |
| DoD = 35%                                       | DoD = 40%                                       |
| Discharge Current =                             | Discharge Current =                             |
| 29.17 Amps for 36 Minutes                       | 40 Amps for 30 Minutes                          |
| Recharge - 104%                                 | Recharge - 104%                                 |
| Charge Current =                                | Charge Current =                                |
| 20.22 Amps for 54 Minutes                       | 26.12 Amps for 46 Minutes                       |
|   | 3.41 Amps for 14 Minutes                        |
| Completed 20615 cycles 3.5 yrs<br>as of 10/1/98 | Completed 13336 cycles 2.3 yrs<br>as of 10/1/98 |

The Life Cycle test conditions are shown above.

The batteries although on slightly different regimes can be compared.

In terms of life the batteries are cycling 1 year apart.



Trend Plot of Voltage vs Cycle for Pack 3003L.

The top line is the End-of-Charge (EOC) voltage.

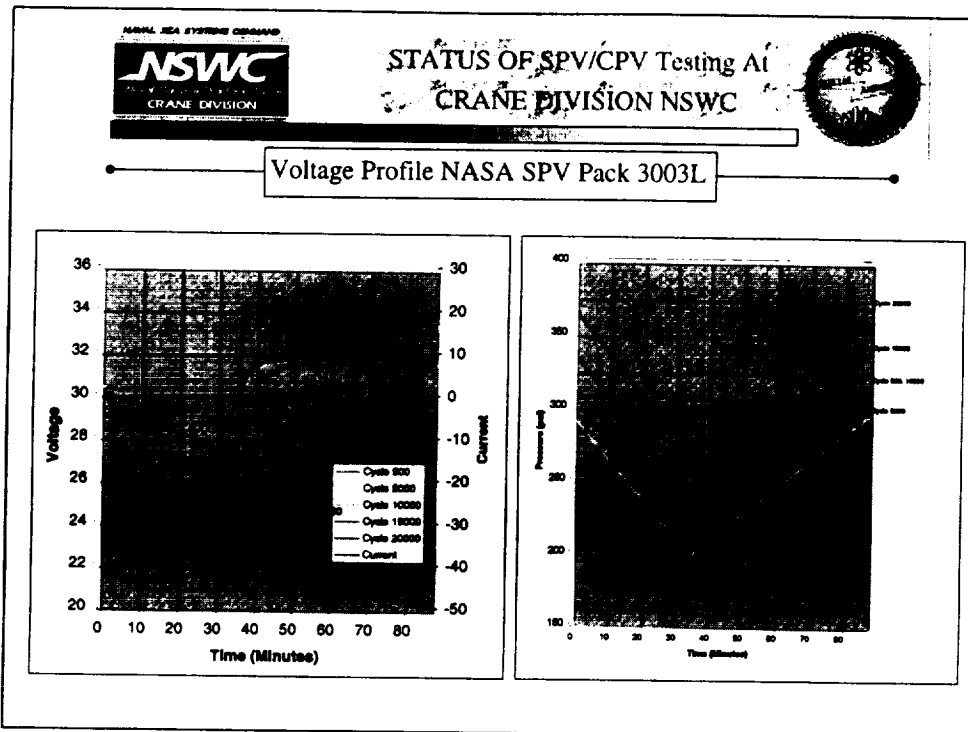
The bottom line is the End-of-Discharge (EOD) voltage

At 26 volts EOD = 1.18 v/cell

At 34 volts EOC = 1.54 v/cell

Trend Plot of Pressure and Recharge vs Cycle for Pack 3003L.

The lower % Recharge may have caused the lower difference in EOD note in previous slide around 20000.



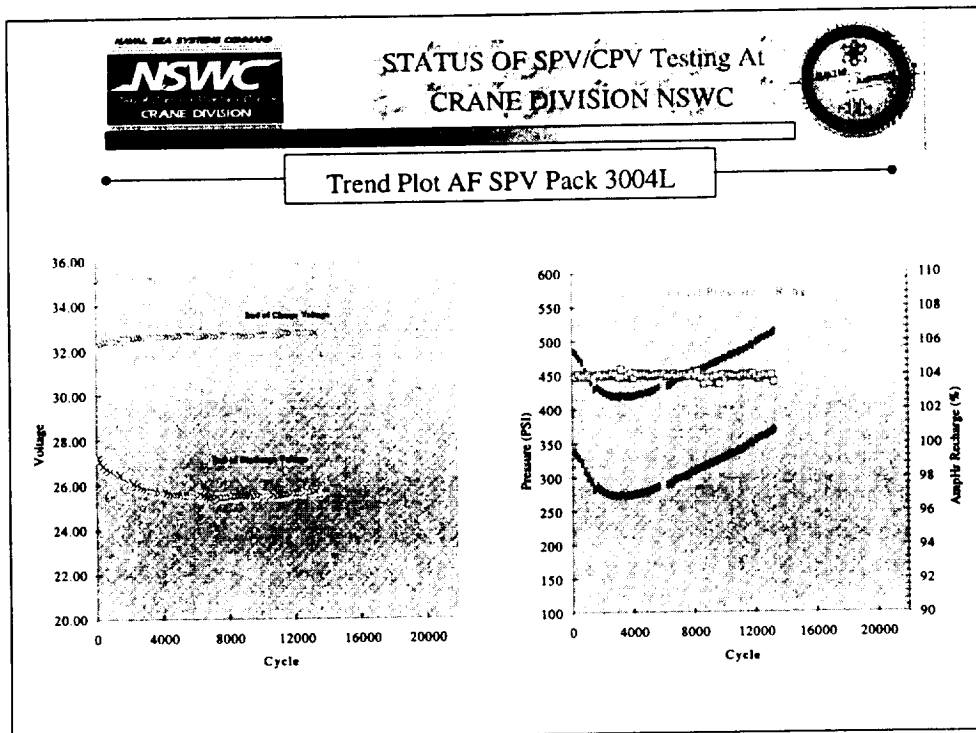
If the curves are not in color: The lowest EOD curve is cycles 20000 and 15000.

Cycles 5000 and 10000 are in the middle, and cycle 500 is the top curve. Note that the as the EOD is lower, EOC increases.

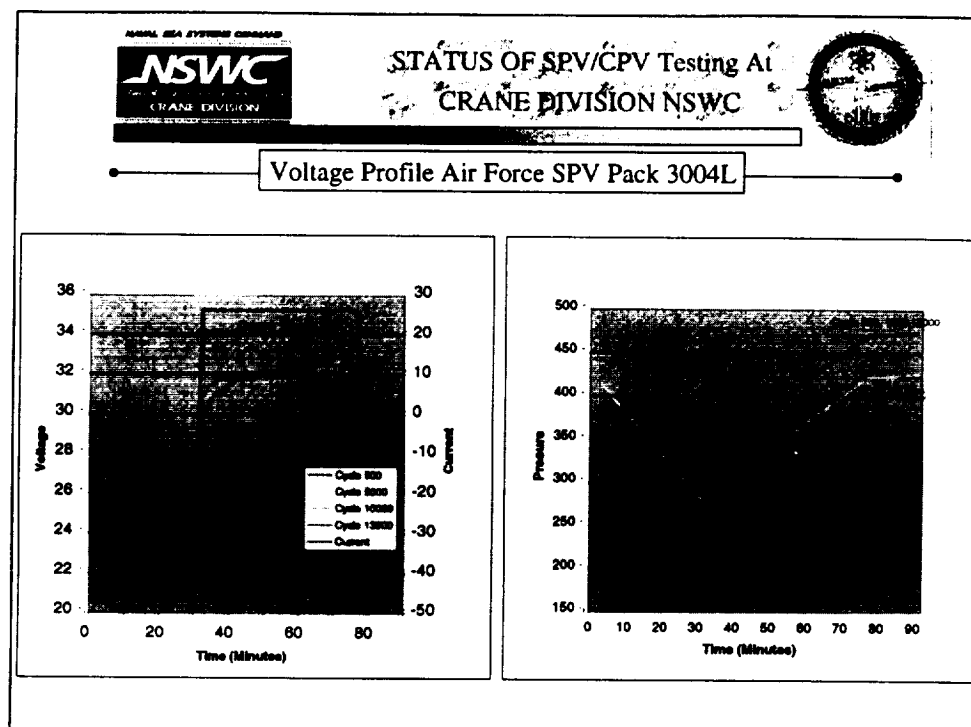
| Cycle | EOD   | EOC   |
|-------|-------|-------|
| 500   | 26.86 | 33.43 |
| 5000  |       |       |
| 10000 | 25.42 | 33.67 |
| 15000 |       |       |
| 20000 | 24.77 | 33.99 |

Pressure change is very consistent. The pressure changes in the first 500 cycles. The curves remain linear. If Pressure is used as a state of charge, a recalibration must be done overtime.

| Cycle | EOC | EDO |
|-------|-----|-----|
| 500   | 314 | 227 |
| 5000  | 292 | 200 |
| 10000 | 314 | 227 |
| 15000 | 335 | 241 |
| 20000 | 365 | 271 |



Voltage, Pressure and % Recharge Trend Plot for PACK 3004L



Voltage Profile for Cycles 500, 5000, 10000, and 13000

Cycle 500      EOD = 26.82    EOC High Rate = 33.44    Trickle = 32.31

Cycle 13000    EOD = 25.47    EOC High Rate = 33.90    Trickle = 32.61

Pressure Profiles for the cycles

Cycles 500, 10000 and 13000 are the upper curve

Cycle 5000 is the lower curve

| Cycle | EOD | EOC |
|-------|-----|-----|
| 500   | 329 | 464 |
| 5000  | 280 | 405 |
| 10000 | 329 | 464 |
| 15000 | 329 | 464 |





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ACKNOWLEDGEMENT

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Air Force Research Laboratory

Battery Program - Ralph James, Dan Radzykewycz

Technical Direction (Air Force)

The Aerospace Corporation - Carole Hill

